

Masers as probes of the gas properties close to forming high-mass stars

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closest collaborators:

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Ciriaco Goddi

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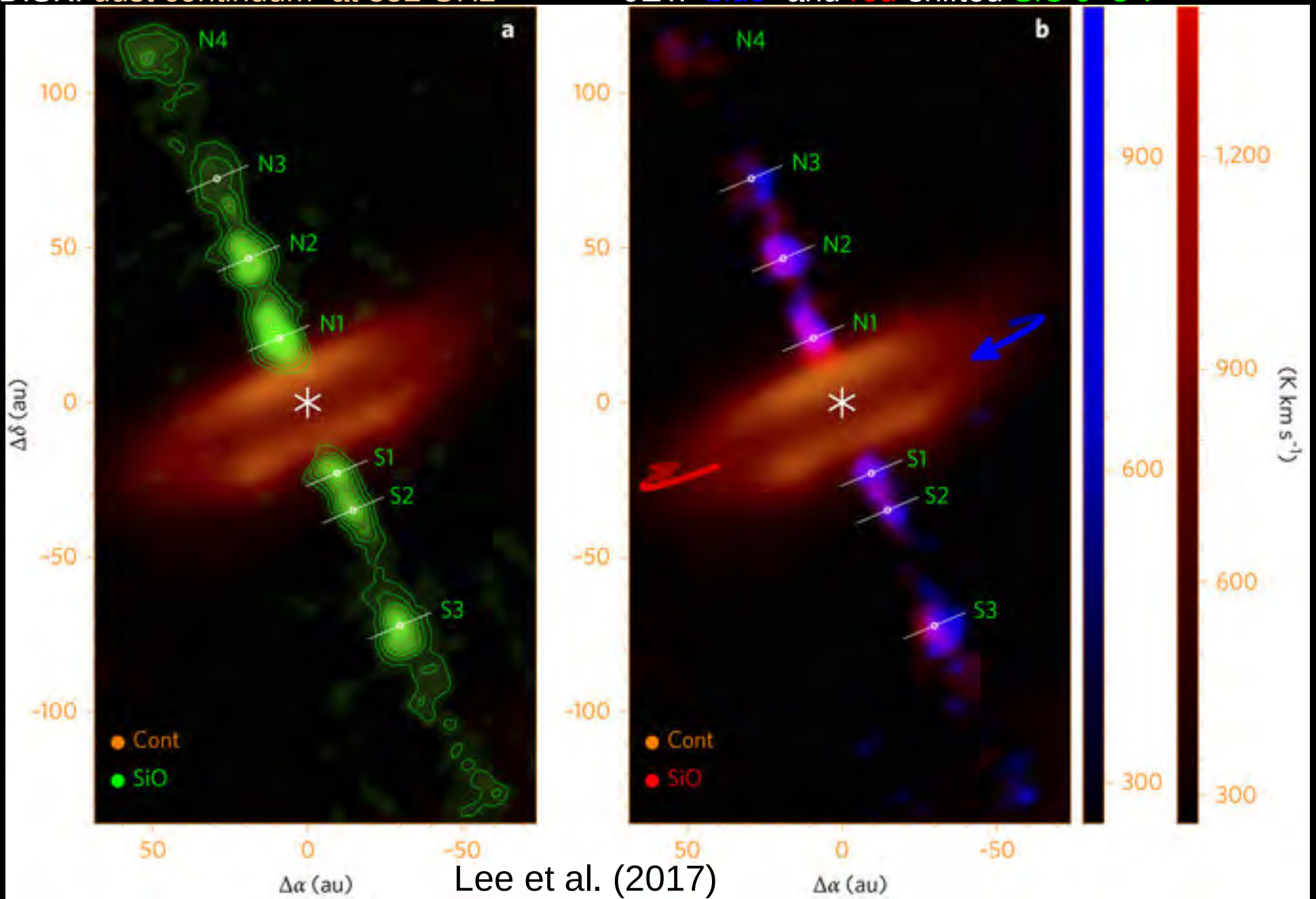
Low-mass (~1 $M_\odot$) Star Formation: Disk+Jet system

HH212: ALMA @ 8 AU & 1 km s^{-1}

DISK: dust continuum at 352 GHz

JET: blue- and red-shifted SiO J=8-7



Lee et al. (2017)

High-mass stars “switch on” still accreting

Impact of radiation pressure and photoionization (thermal pressure from HII regions) on the accretion of circumstellar gas

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B-type YSOs with disks. Few (claims of) disks towards O-type YSOs

A few thermal jets towards high-mass YSOs (VLA, rms ~ 0.3 mJy)

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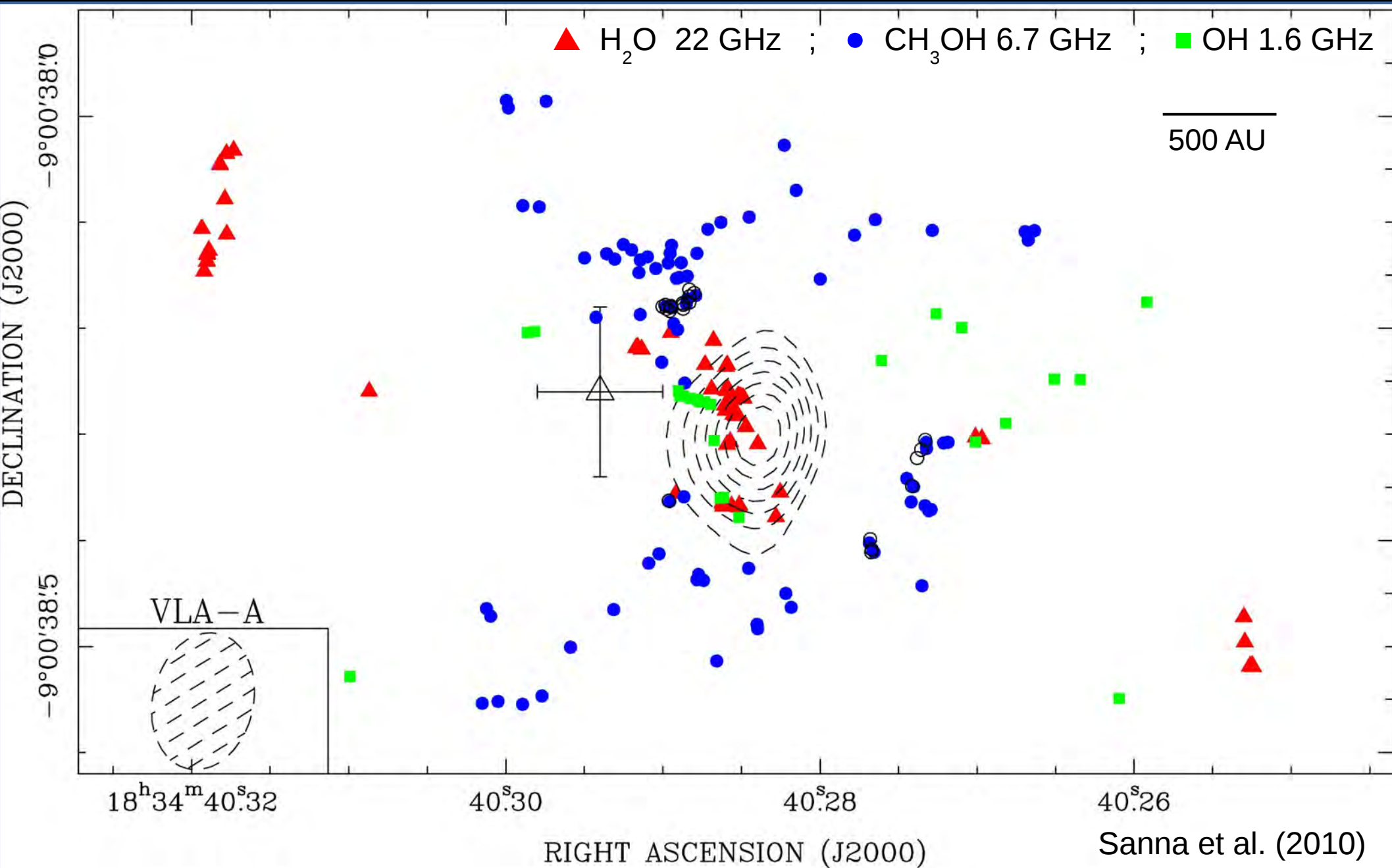
Observations of high-mass YSOs are challenging:

- High extinction => Optical and NIR impossible
- Formation in clusters => Confusion/crowding
- Declining IMF and Rapid evolution: Large Distances (> 1 kpc)

Strong Molecular Masers in High-Mass SF Regions

Spatial Distribution of Molecular Masers in G23.01-0.41



Sanna et al. (2010)

TALK OUTLINE

1) Ejection process, i.e. jets/winds, in high-mass YSOs at radii of ~100 AU studied by means of water masers.

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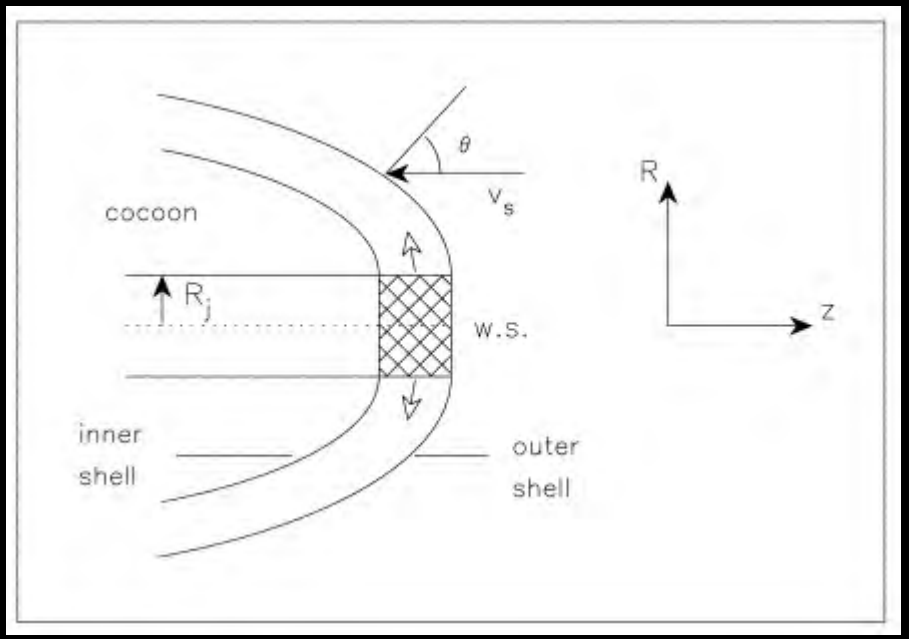
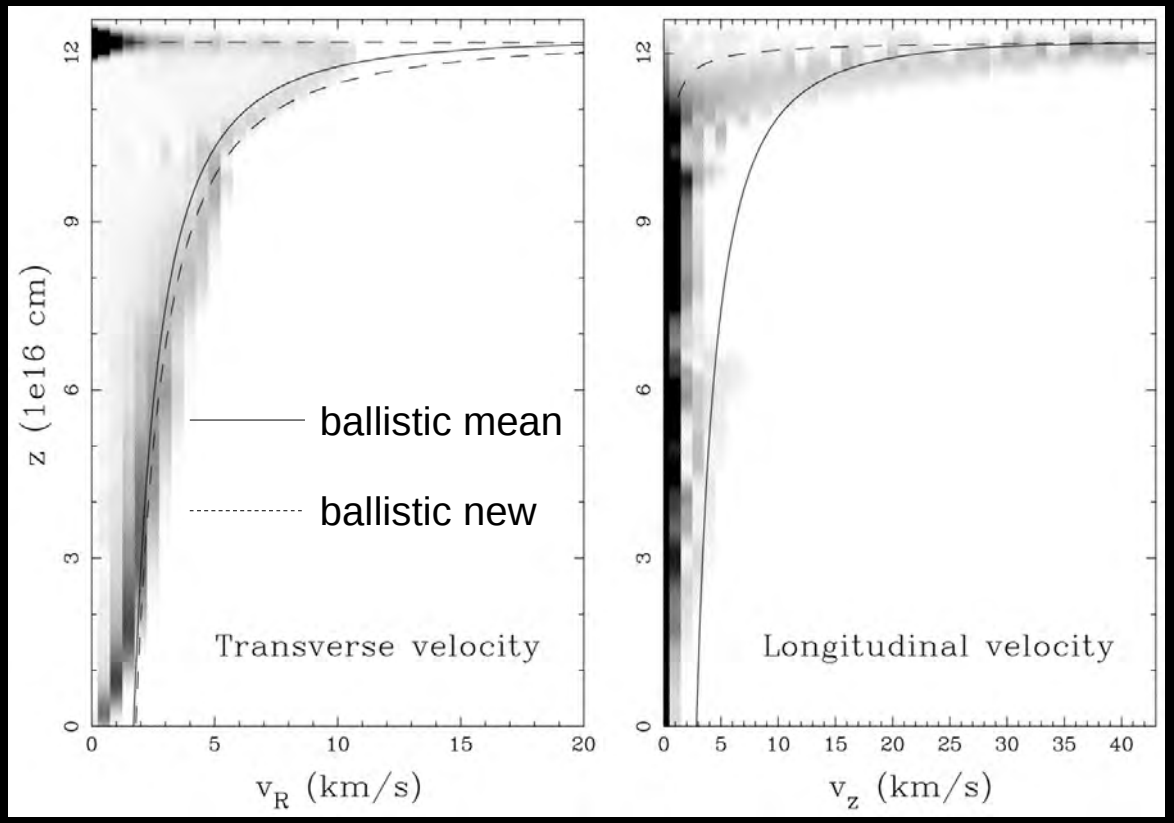
2) The jet/disk system in high-mass YSOs unveiled by water and methanol masers.

Outflow structure within 1000 AU from high-mass YSOs

(collimated)

JET-driven shell





(wide-angle)

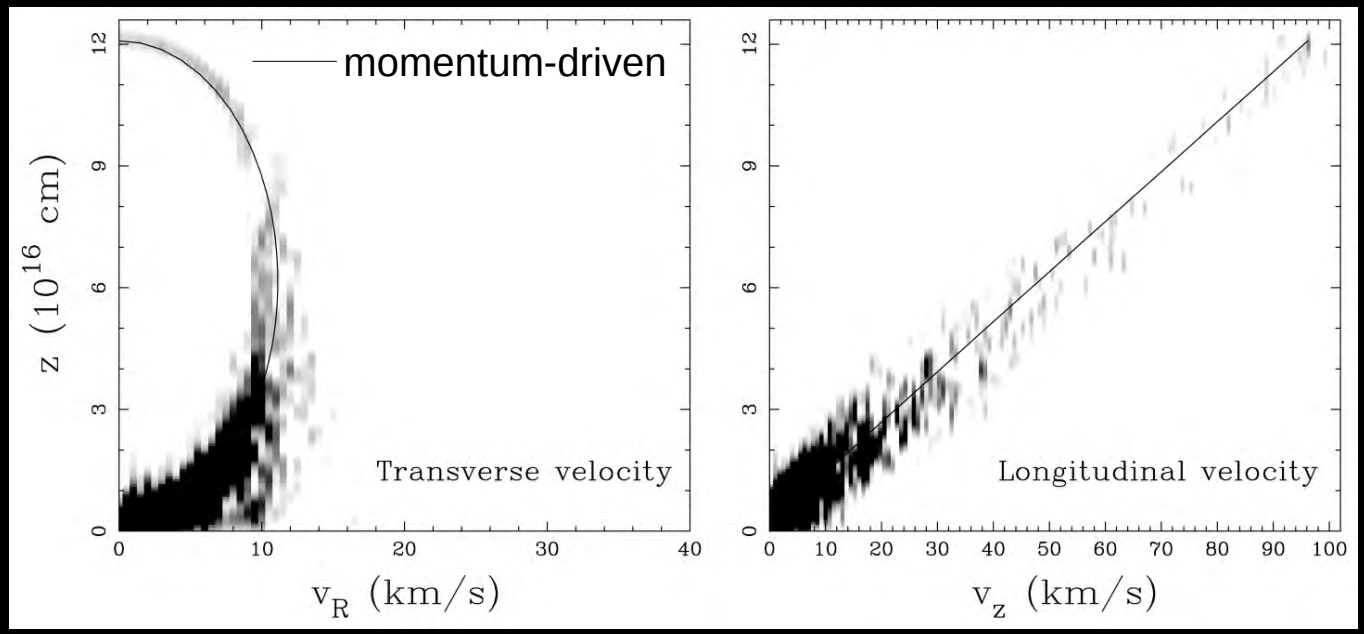
WIND-driven shell

2-D hydrodinamic simulations

and analytic models

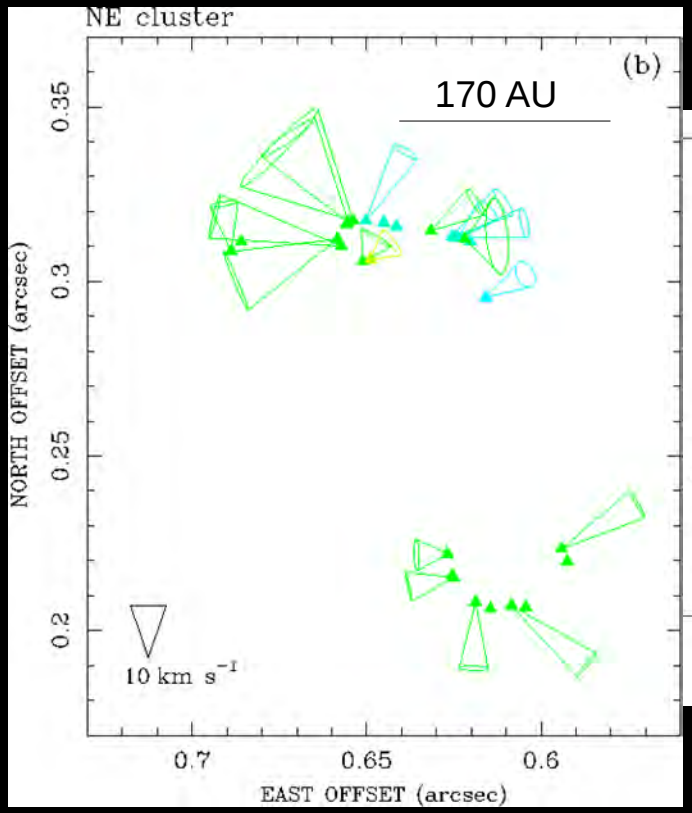
Lee et al. 2001

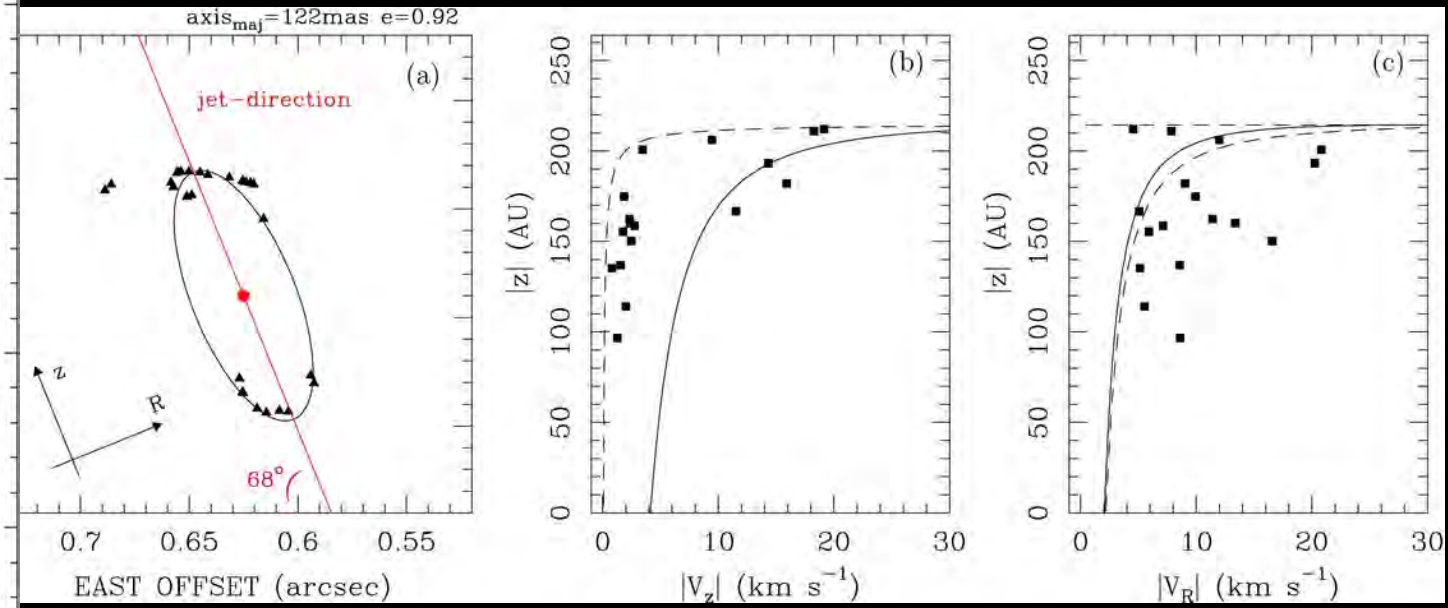
Ostriker et al. 2001



Outflow structure within 1000 AU from high-mass YSOs

AFGL2591 NE (Sanna et al. 2012, see also Torrelles et al. 2014)





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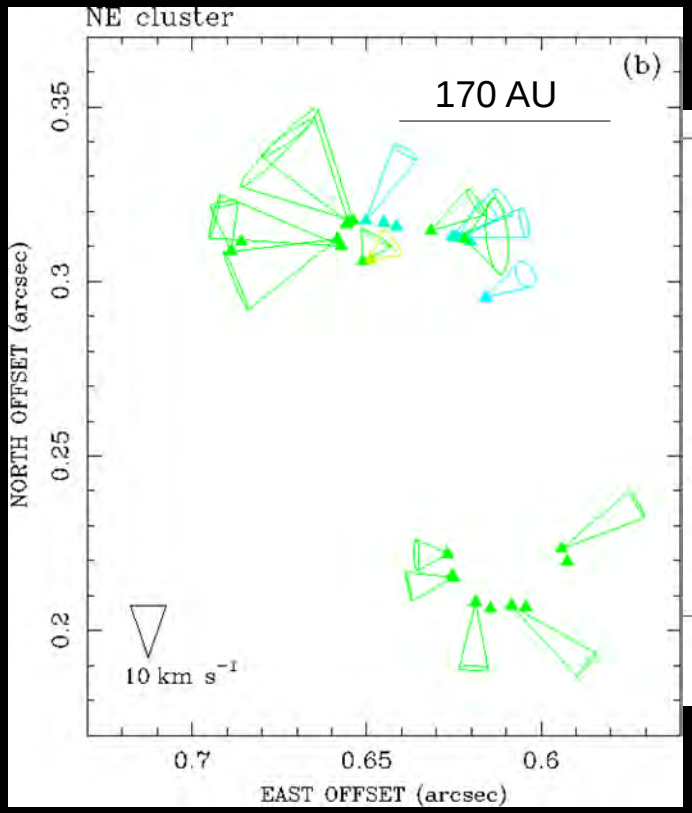
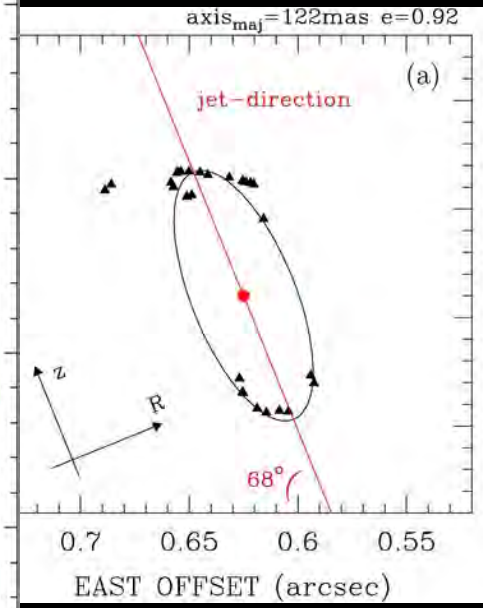
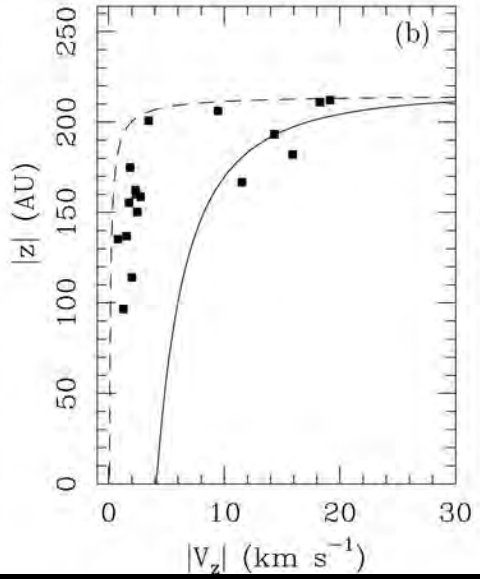
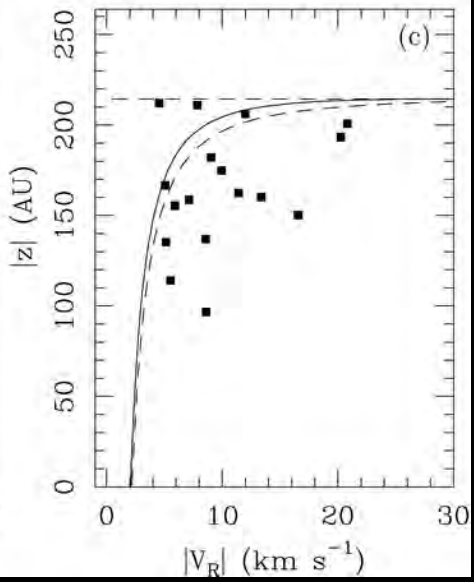
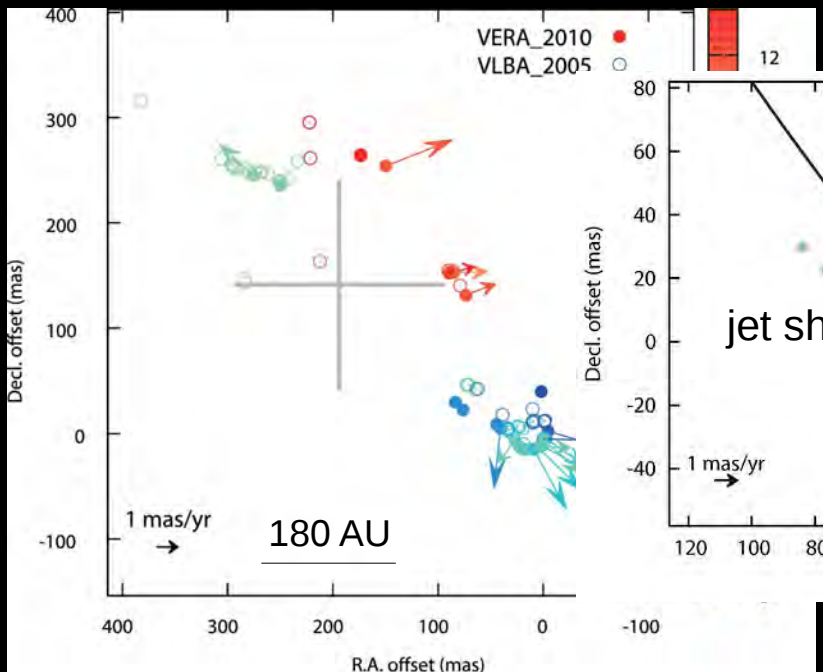


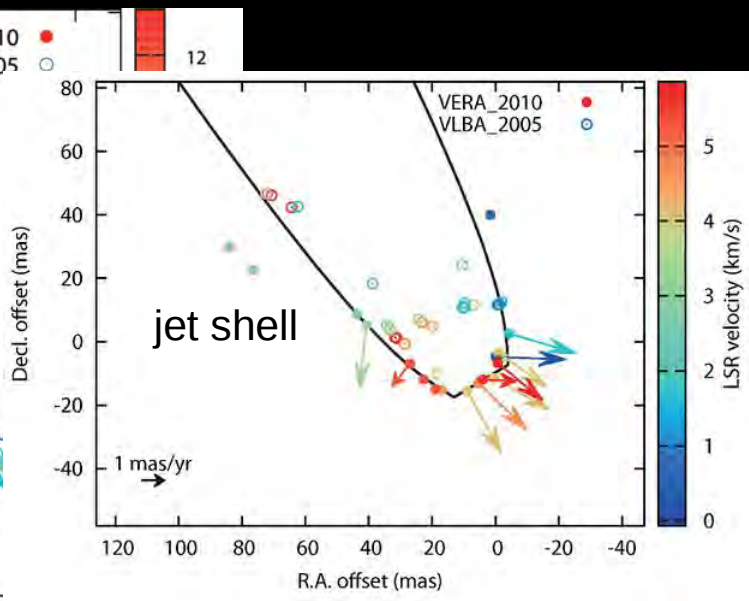


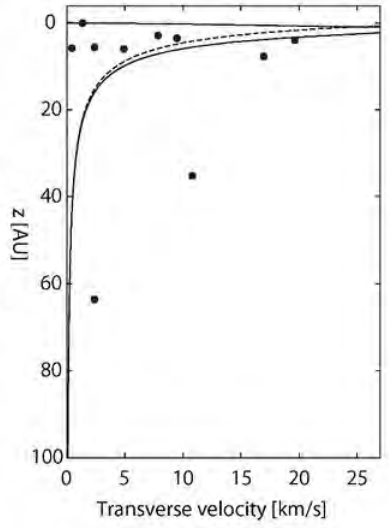


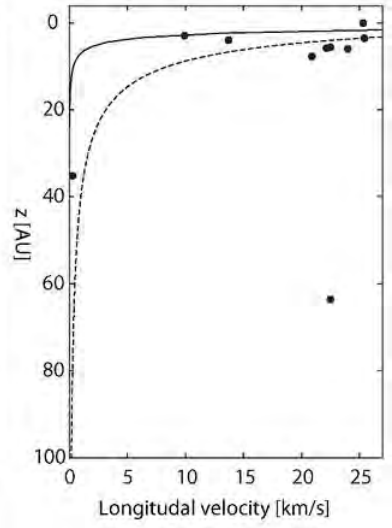


S255IR-SMA1 (Burns et al. 2016)







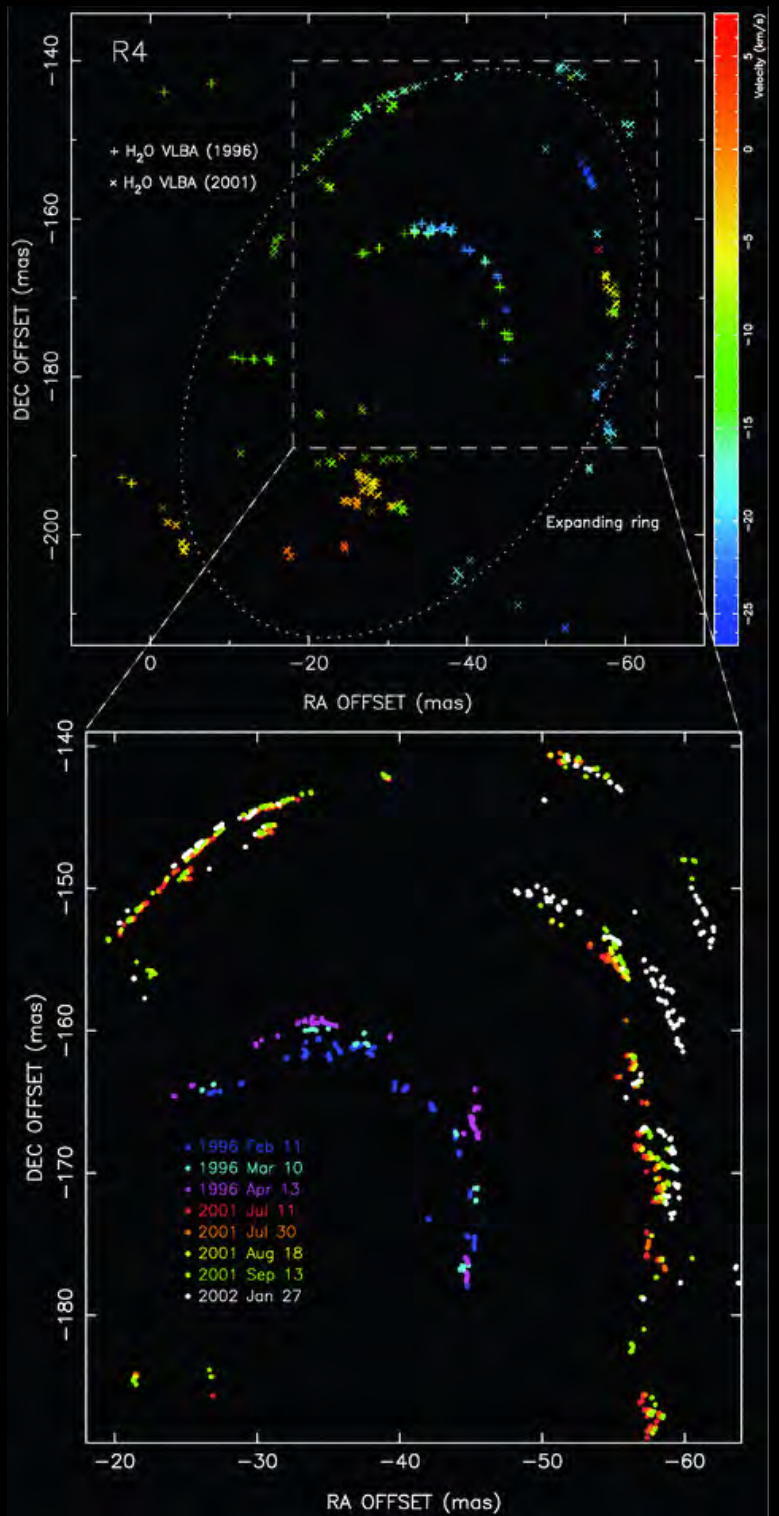


Outflow structure within 1000 AU from high-mass YSOs

Cepheus A HW2 system

ring radius ~ 25 AU

V_{exp} ~ 15 km s^{-1}



Torrelles et al. 2011

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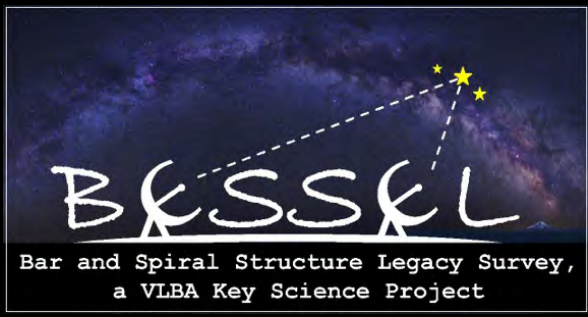
The JVLA/BeSSeL survey of massive outflows



Advantages with respect to previous surveys of massive outflows:

1) using water masers to study 3-D kinematics on scales of 10-100 AU

2) (relatively) large sample of 40 HMYSOs (B3-O7) extracted from the

3) ionized component observed through sensitive JVLA observations
   rms ~ 10 μJy (> 10 times better than previous surveys !)

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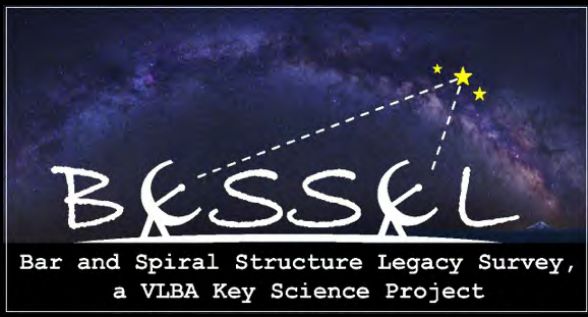

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A-array at 6 GHz (beam ~ 0.4") and 13 GHz (beam ~ 0.2")

B-array at 22 GHz: beam ~ 0.4" (not to resolve the emission and optimum for spectral index)

At 6 and 22 GHz, methanol and water masers are also observed (ΔV = 45, 13 → 0.2 km s^{-1})



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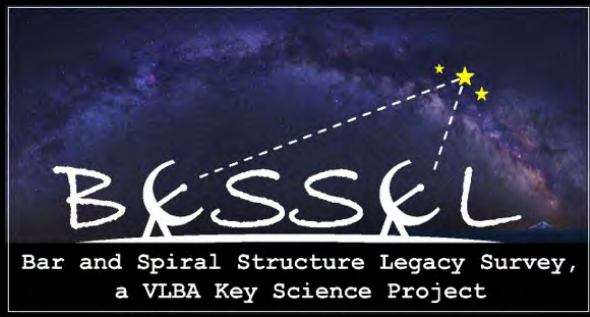

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Continuum data reduction : completed

Publications: First subset (11 targets) in 2016; Full sample in 2018.



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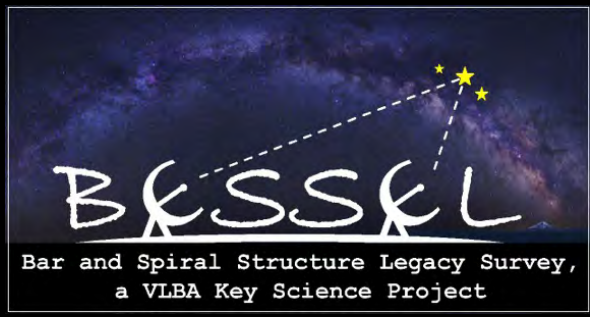

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Large majority of targets detected (~100 μJy) at one or more frequency.

Most detections are compact sources (YSOs) associated with the water masers.

Positive spectral index at 13-22GHz consistent with ionized winds.

A few negative spectral indexes at 6-13 GHz, hinting at synchrotron emission.

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Bar and Spiral Structure Legacy Survey, a VLBA Key Science Project

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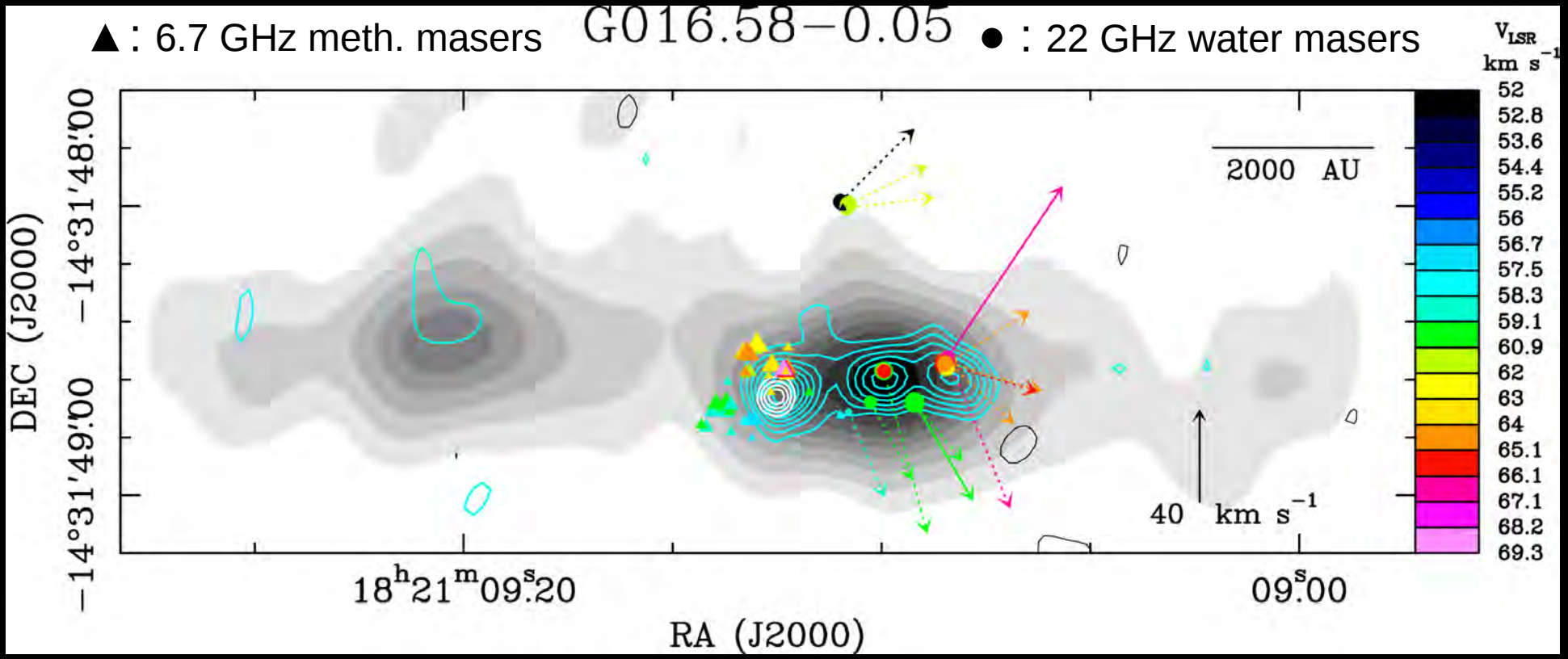
Poster n. 18 by Fabrizio Massi for LBT follow-up

The JVLA/BeSSeL survey of massive outflows: G16.58-0.05

continuum (JVLA, A-Array)

6 GHz 13 GHz 22 GHz



Sanna et al. (2010)

Moscadelli et al. (2016)

The JVLA/BeSSeL survey of m

continuum (JVLA, A-Array)

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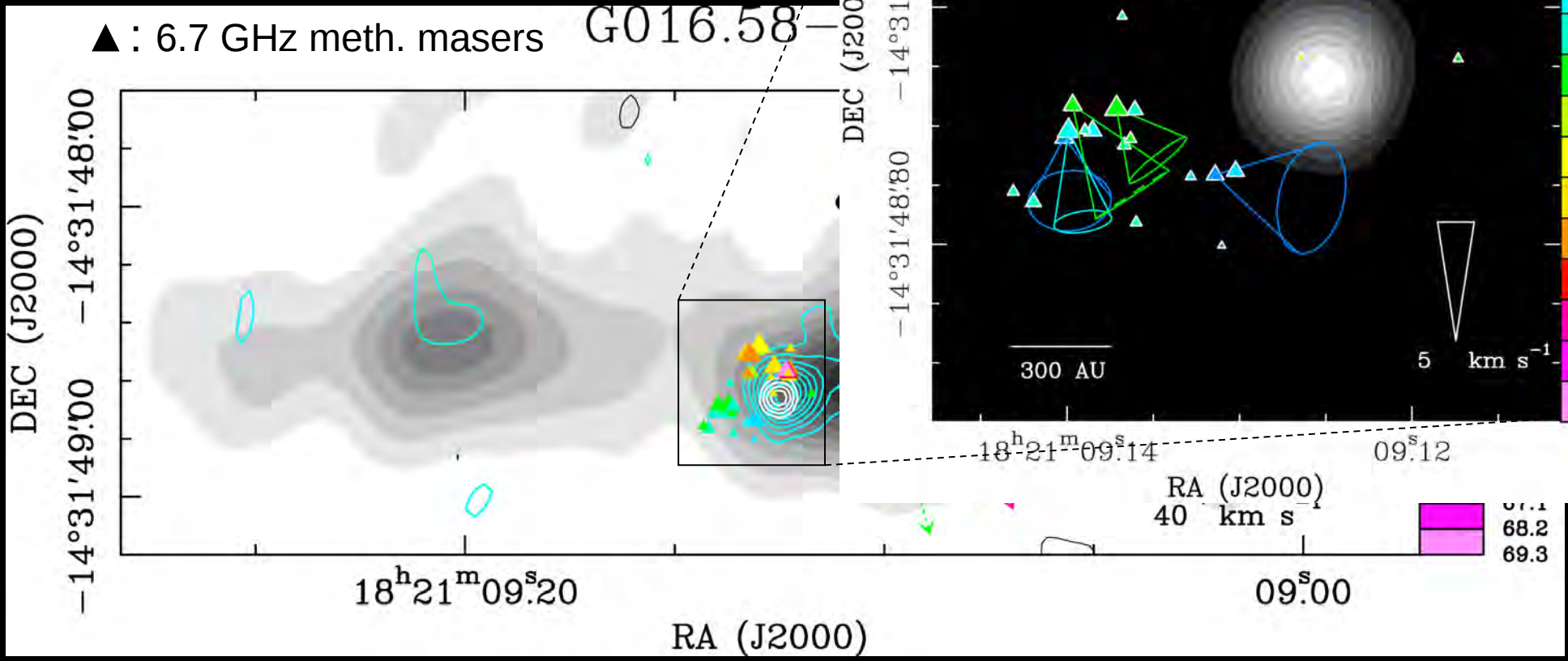

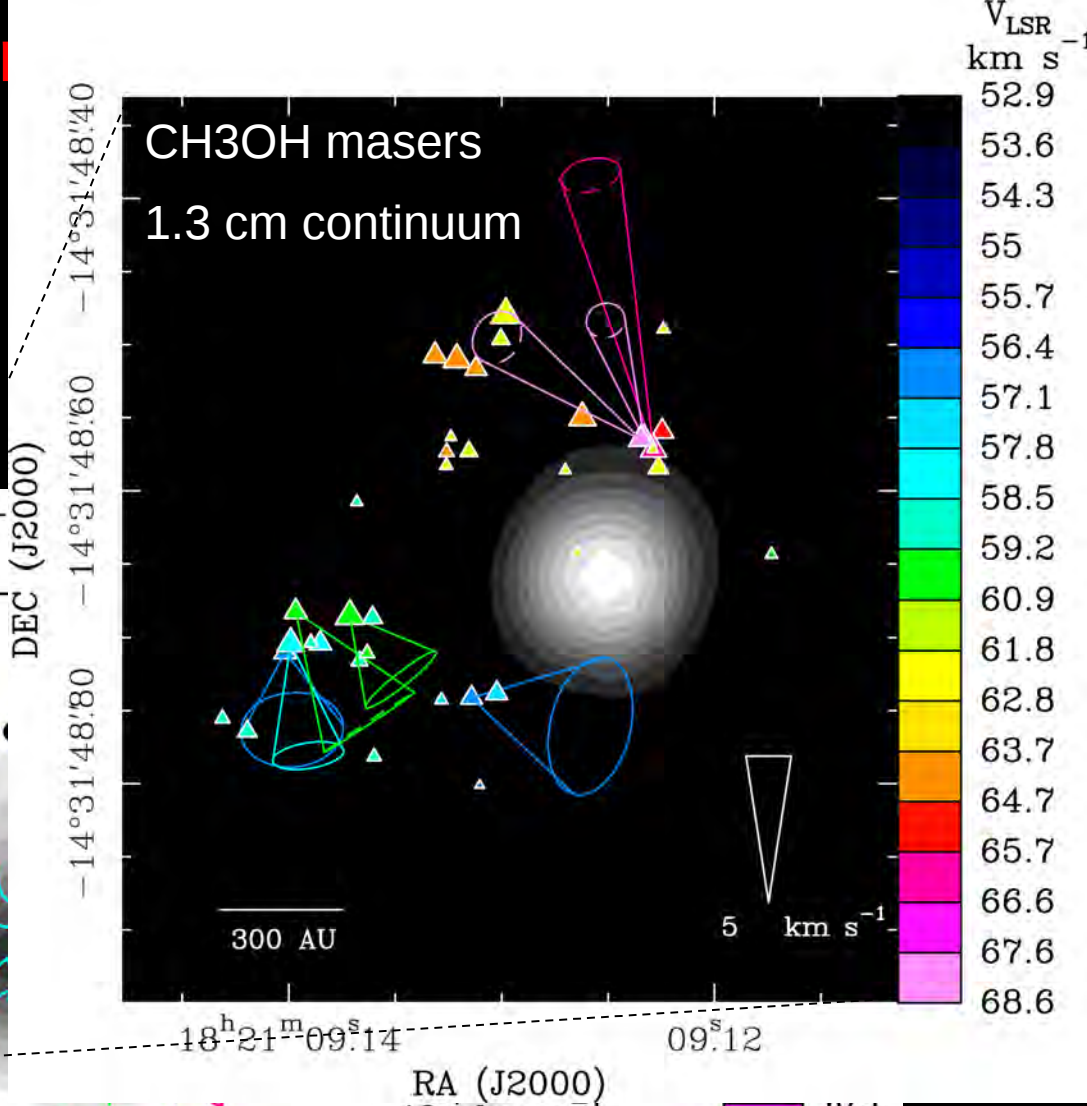

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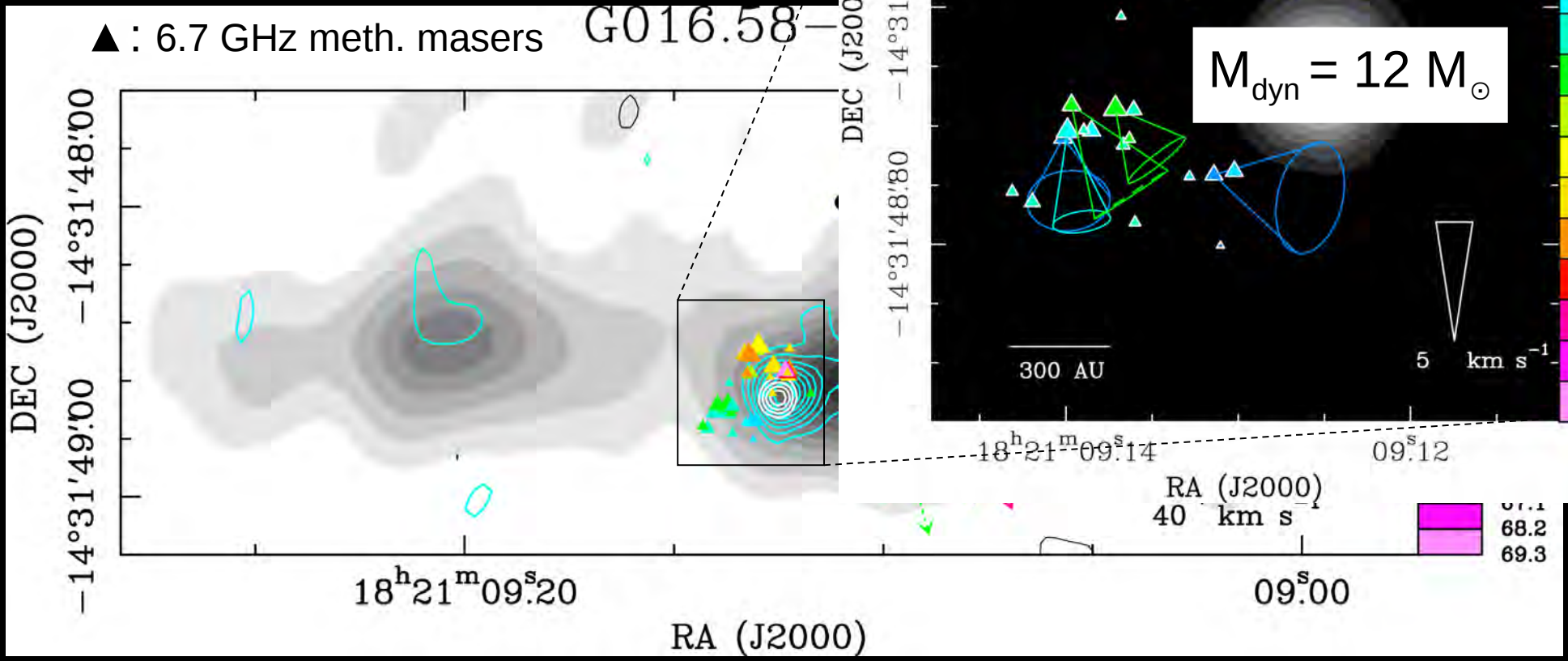

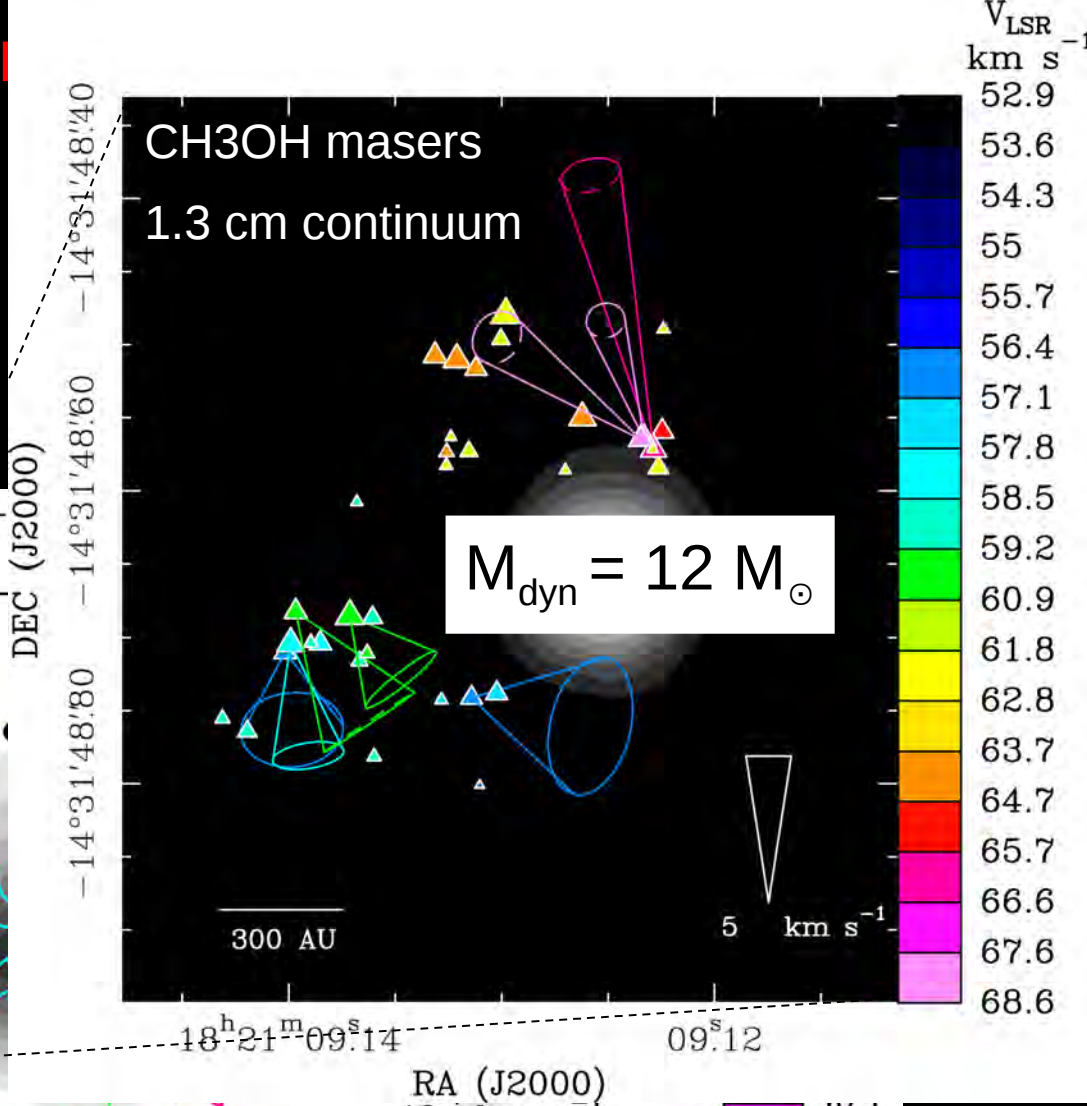

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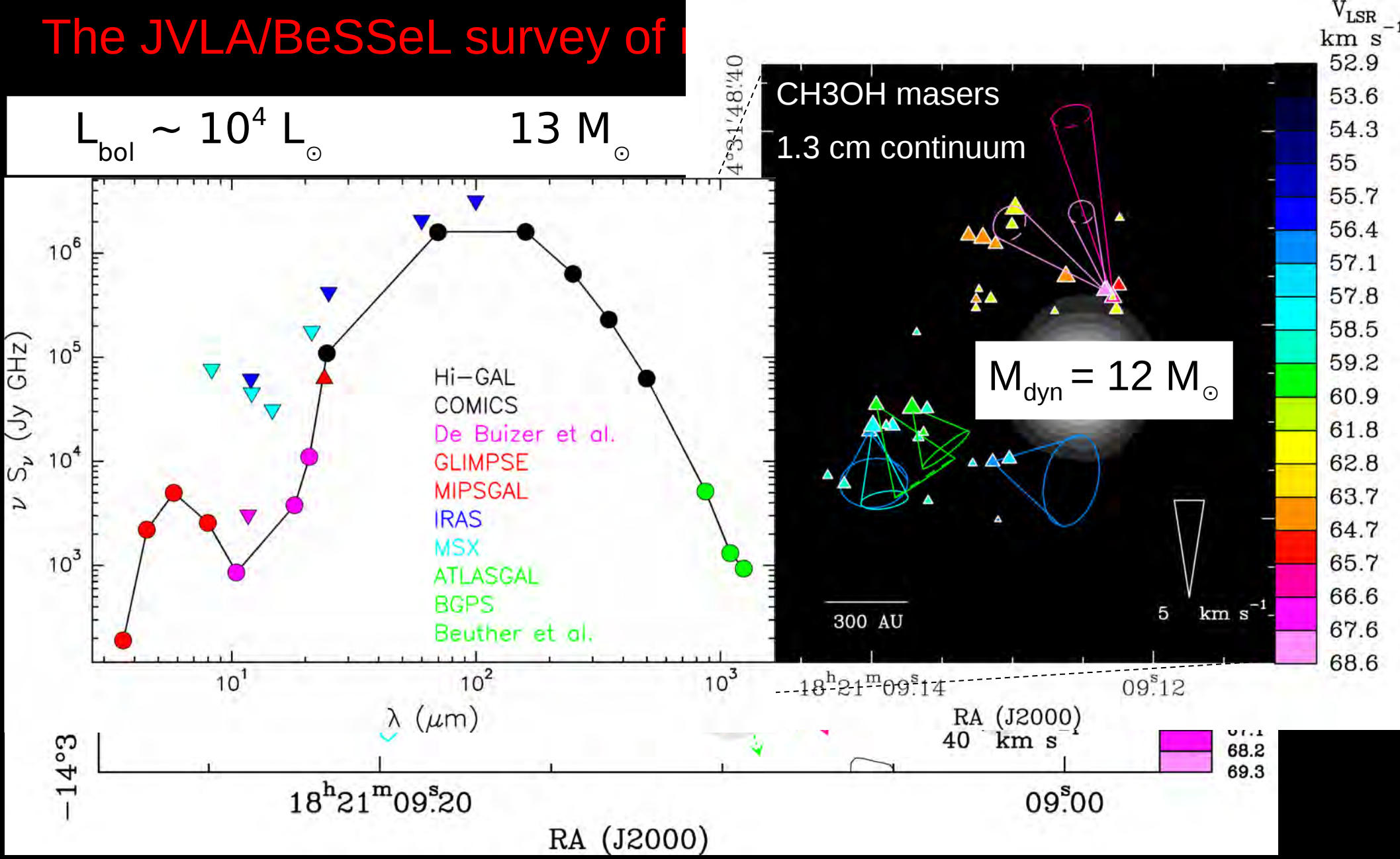
The JVLA/BeSSeL survey of m

$L_{bol} \sim 10^4\ L_\odot$ 13 $M_\odot$



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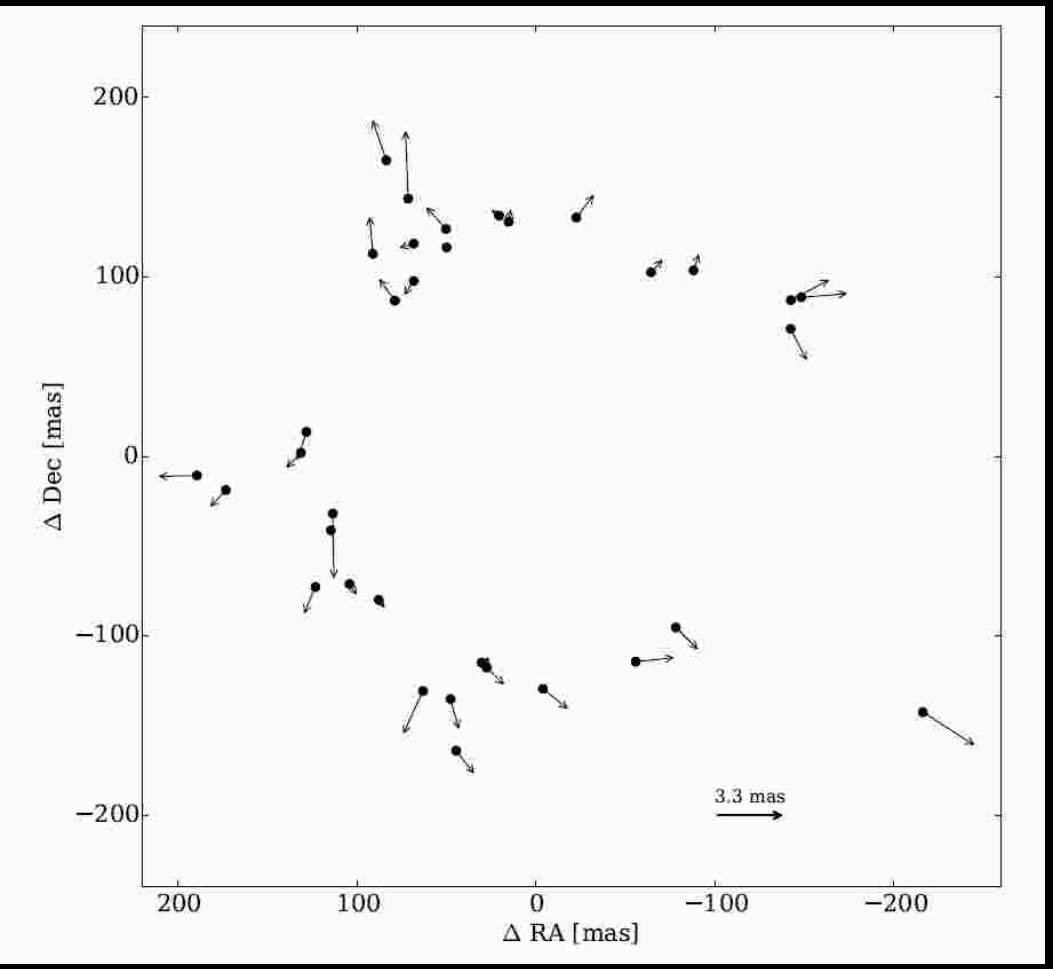
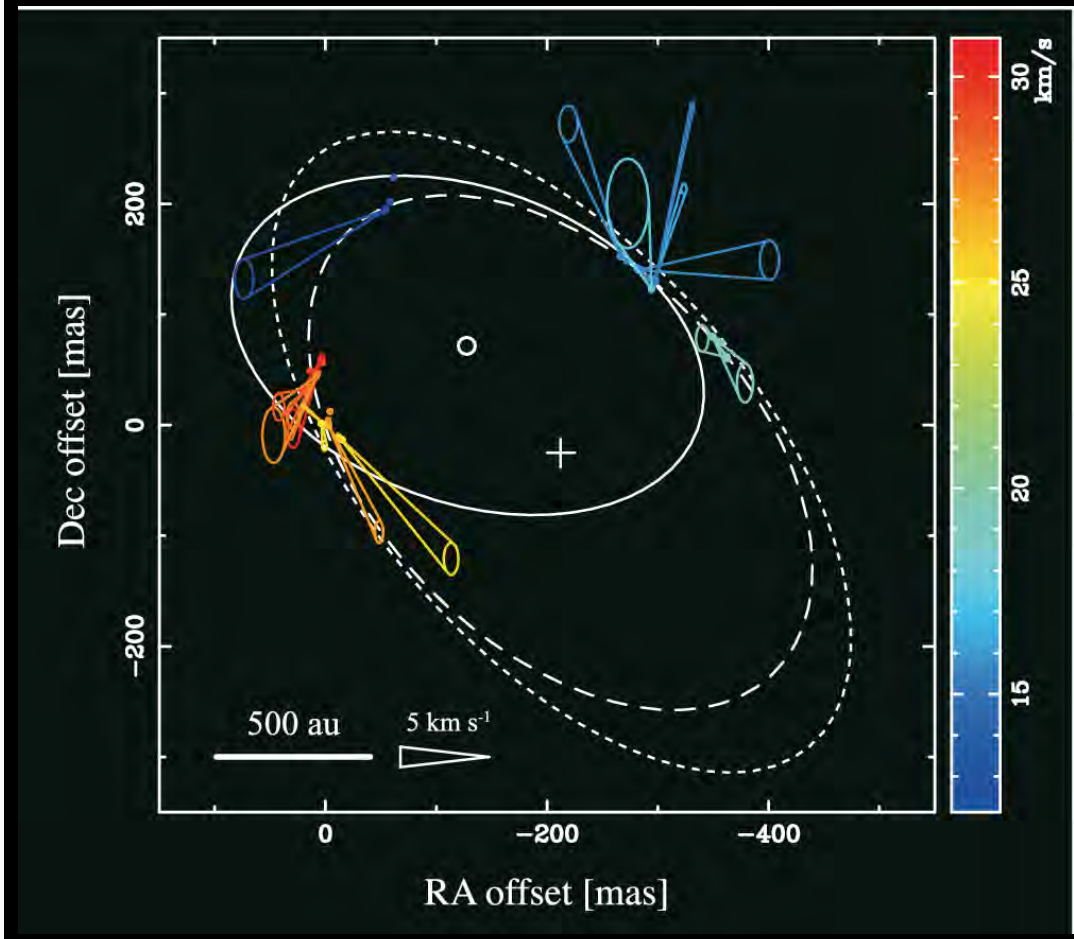
Masers tracing disk/jet in high-mass YSOs

Rotation and expansion traced with VLBI of 6.7 GHz methanol masers

G23.657-00.127 (EVN, Bartkiewicz et al. 2014)



G006.79-00.25 (EAVN, Sugiyama et al. 2016)



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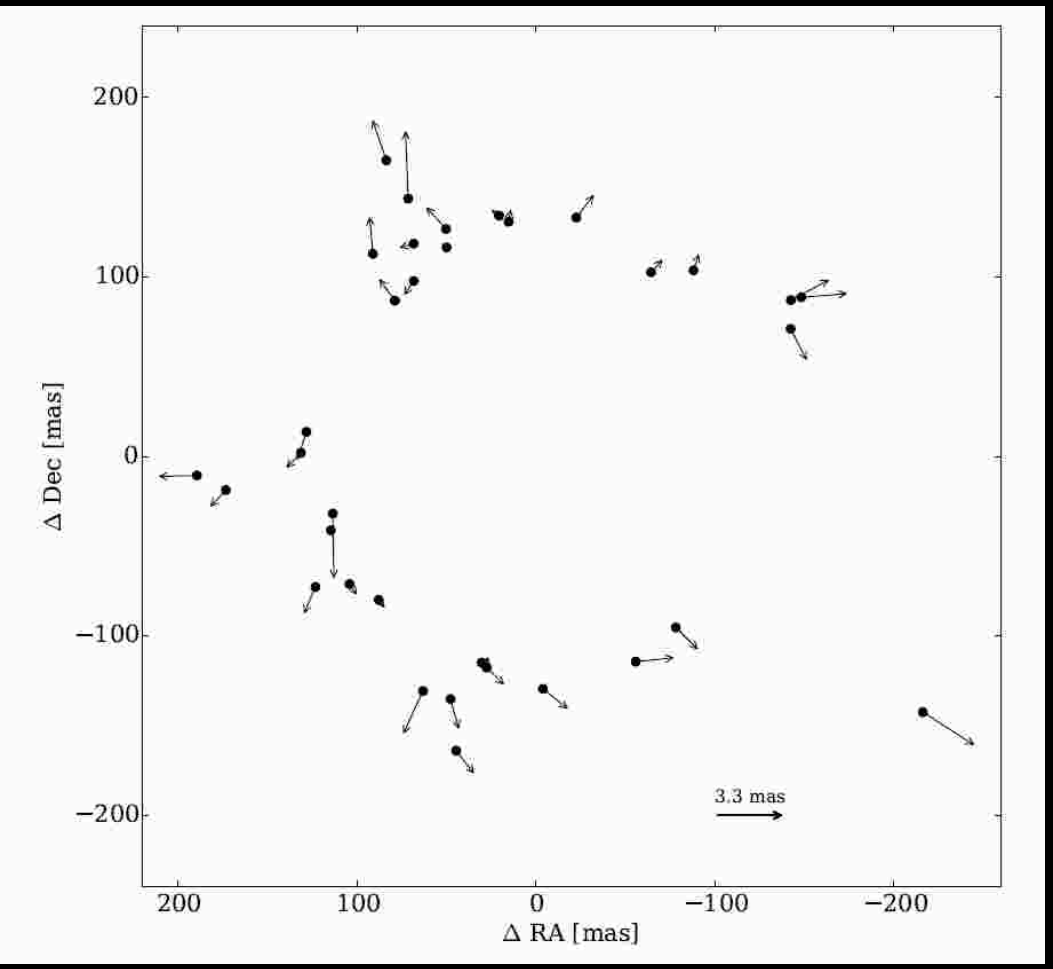

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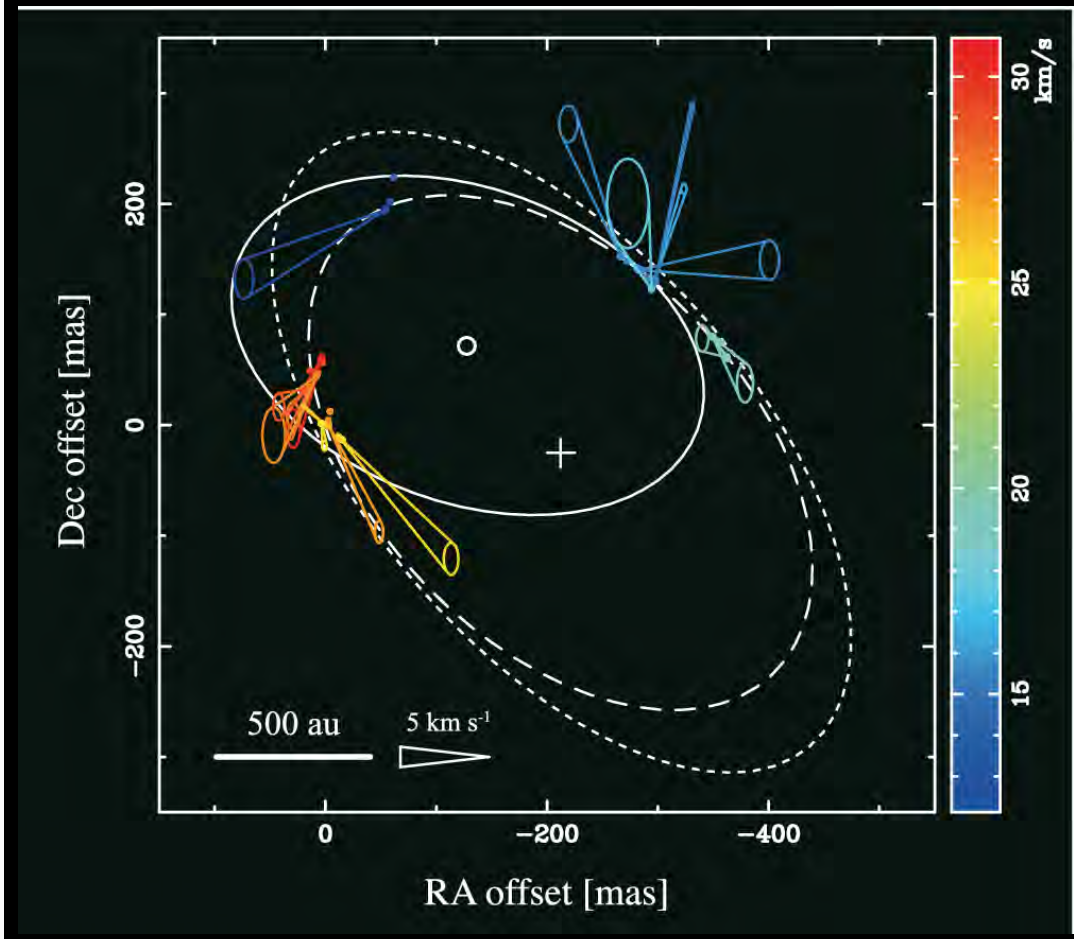
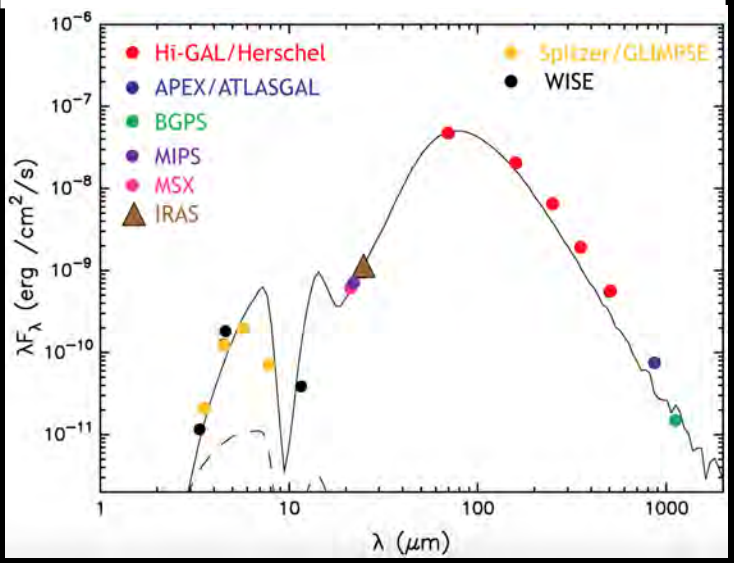


To exploit the maser information, complement the VLBI maser observations with subarcsecond (mm) interferometric data of continuum and thermal lines.

Masers tracing disk/jet in high-mass YSOs: G23.01-0.41

$L_{bol} \sim 4 \times 10^4\ L_\odot$ 19 $M_\odot$



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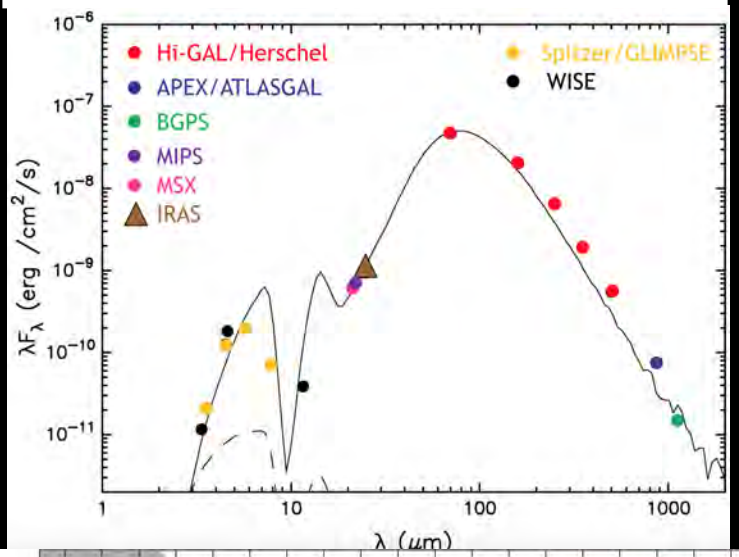

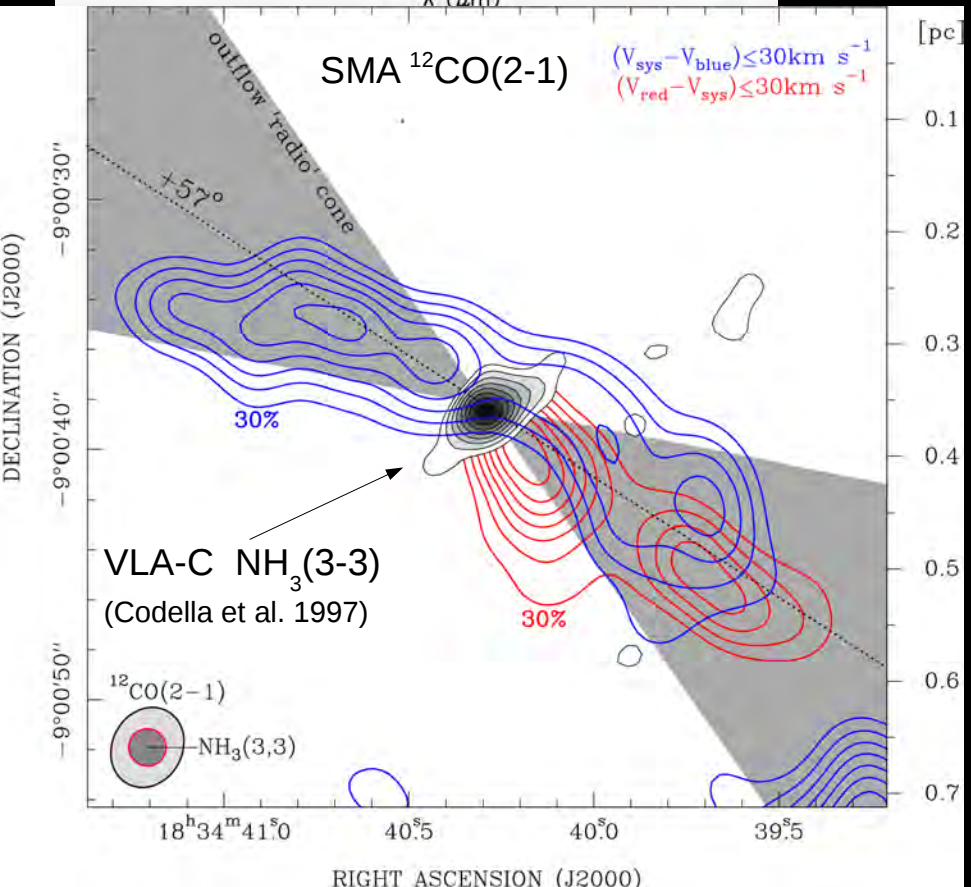

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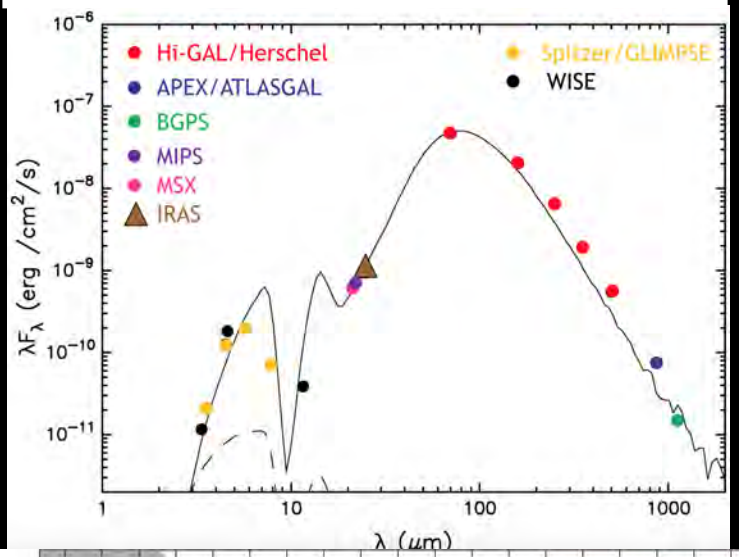
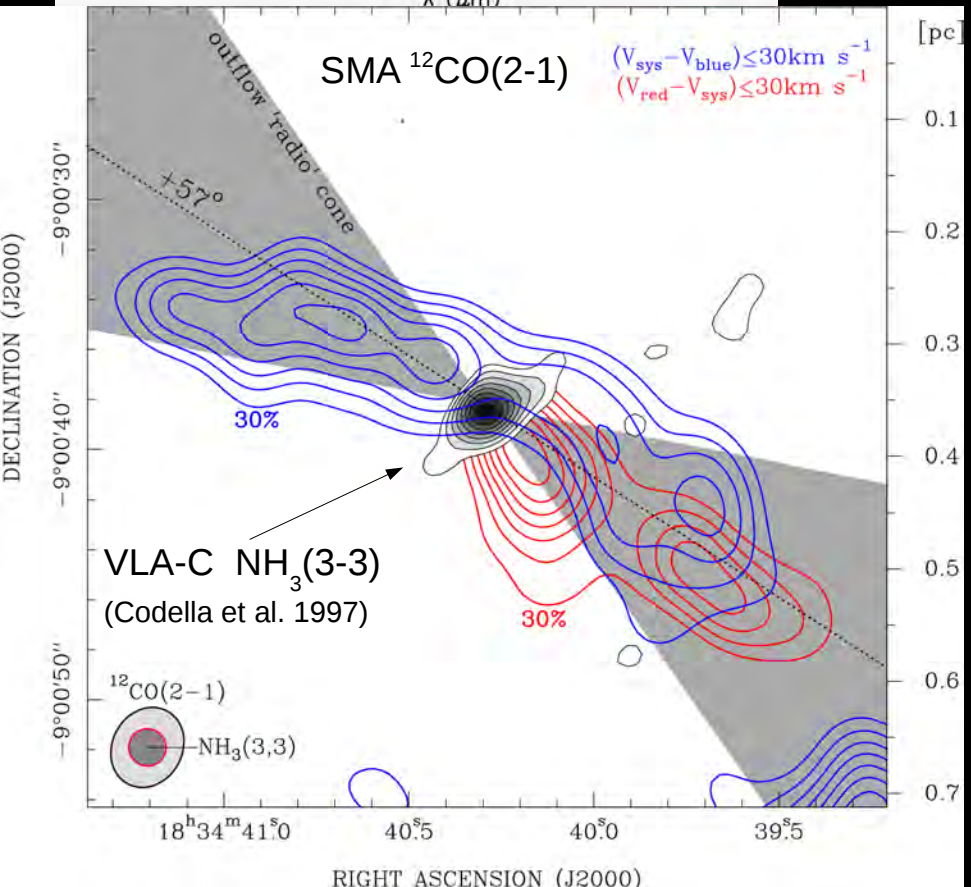
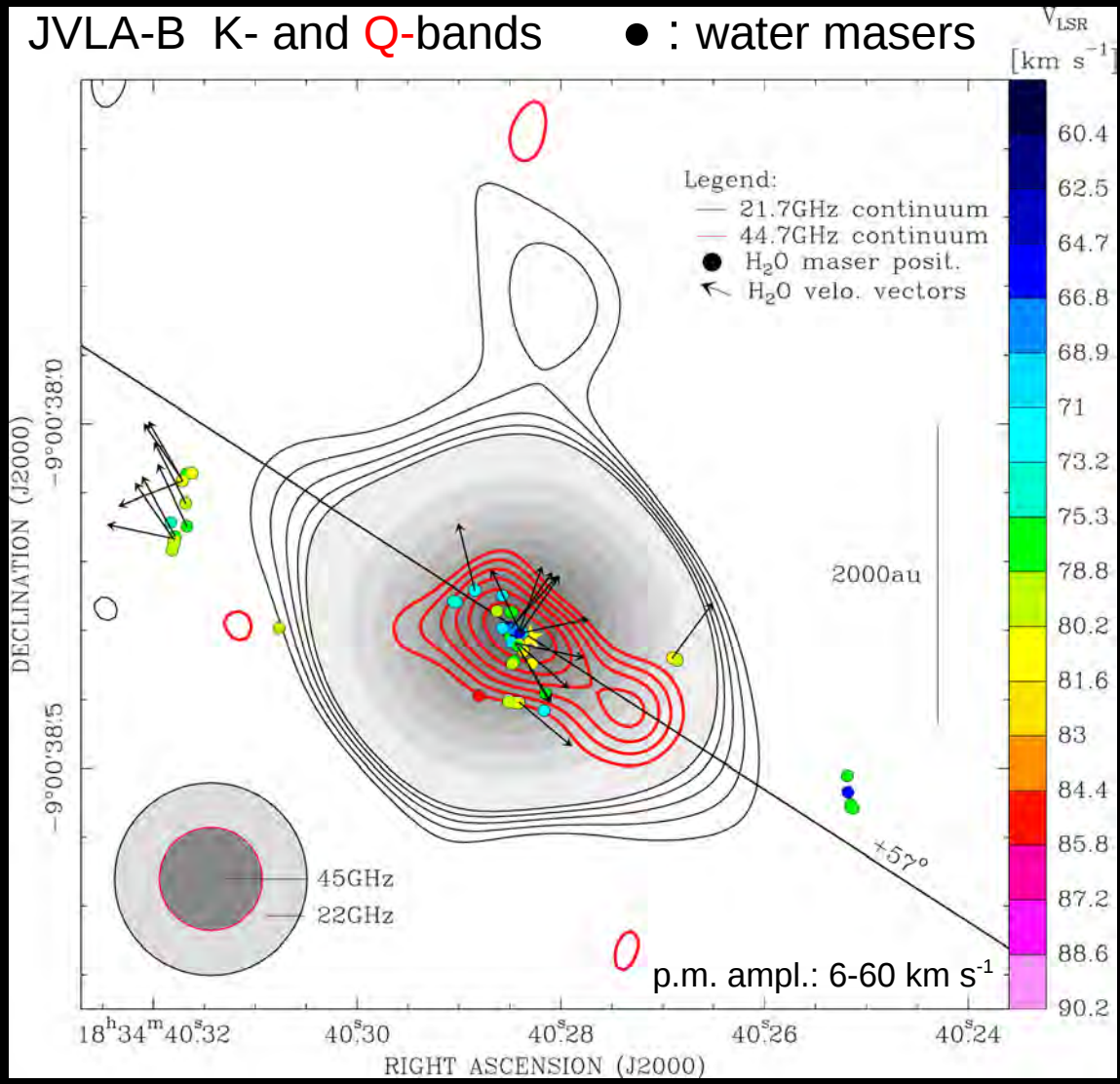
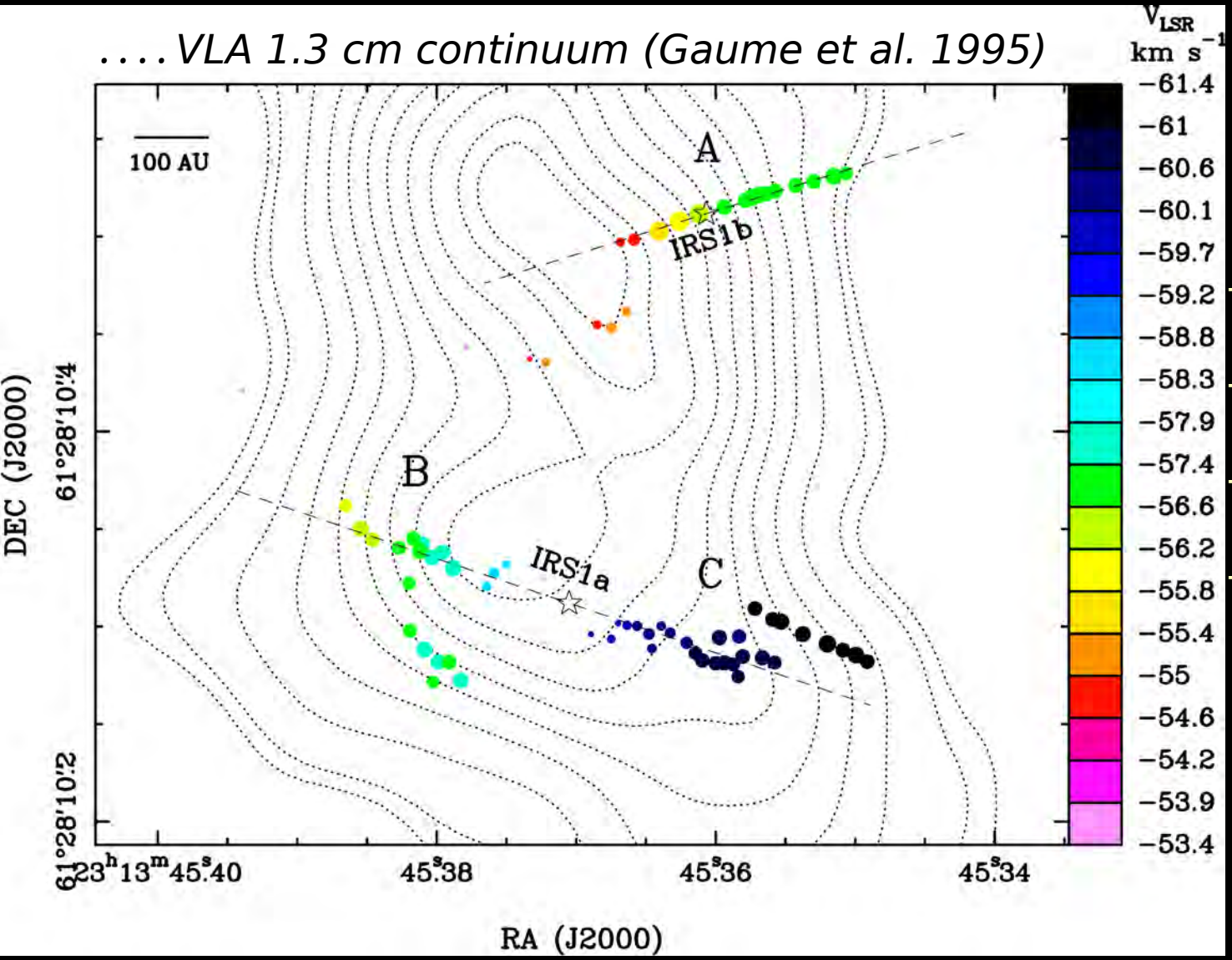






Sanna et al. (2014, 2016)

Masers tracing disk/jet in high-mass YSOs: NGC7538 IRS1



Maser clusters show:

-two linear distributions

-regular l.o.s. vel. gradient

- p.m. aligned along axis

- regular l.o.s. accelerat.

JVLA-B NH3 kinematics consistent with meth. masers

Moscadelli & Goddi 2014

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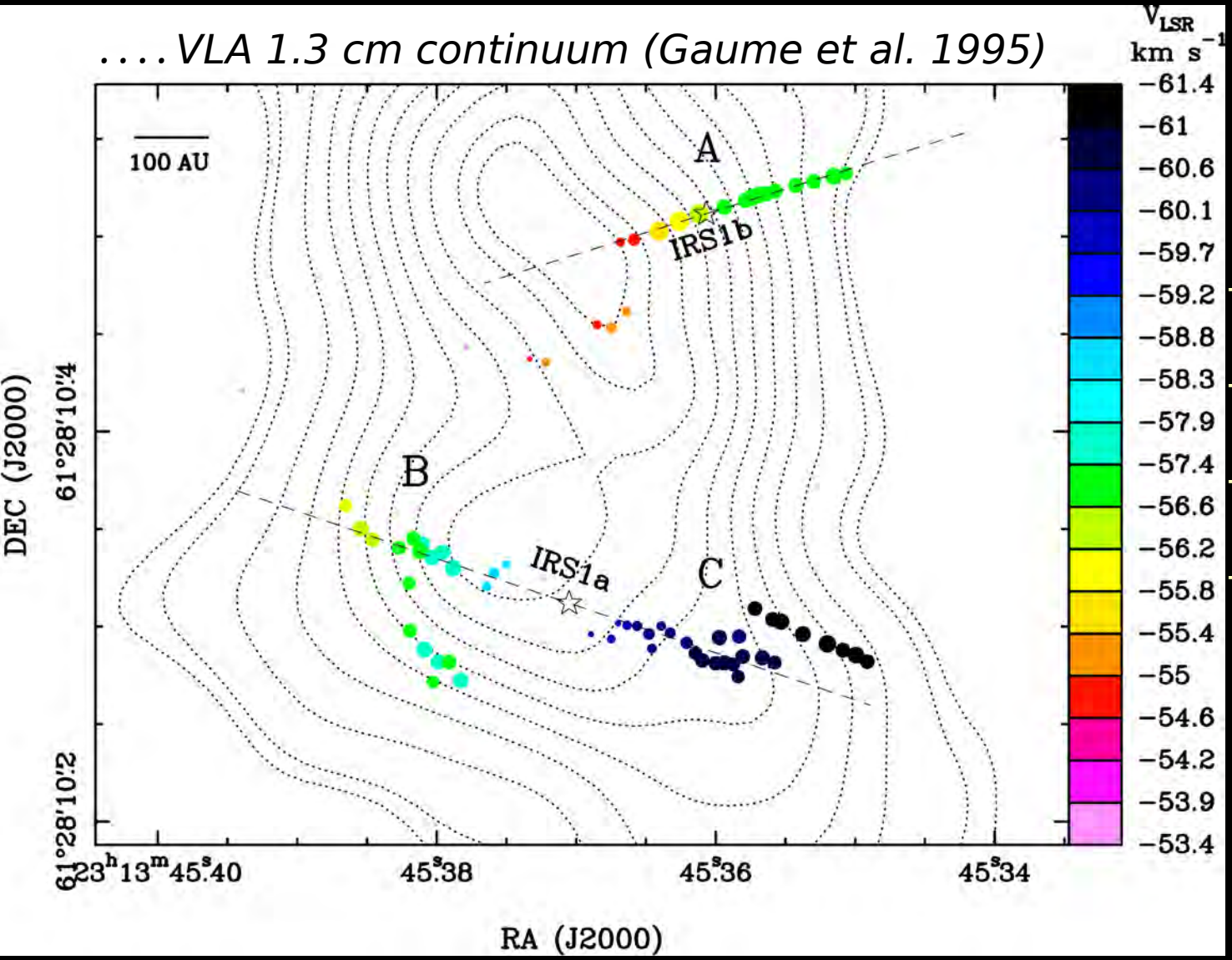

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Our hypothesis: Two massive YSOs surrounded by edge-on disks

Moscadelli & Goddi 2014

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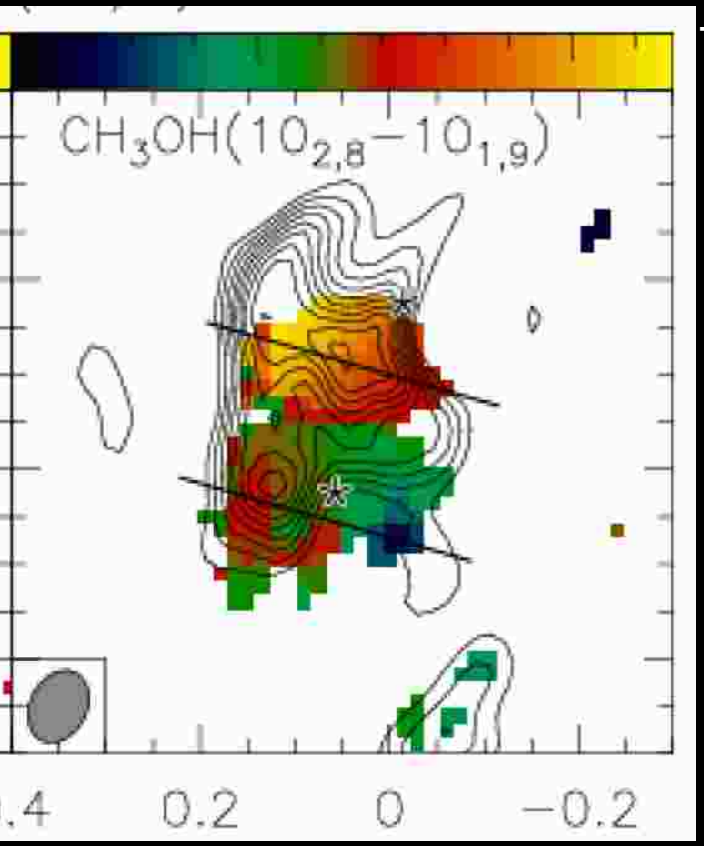

Two vel. gradients in CH_3OH absorption at the meth. maser posit.

using the JVLA-A at ang. res. ≈ 50-60 mas (Beuther et al. 2017)

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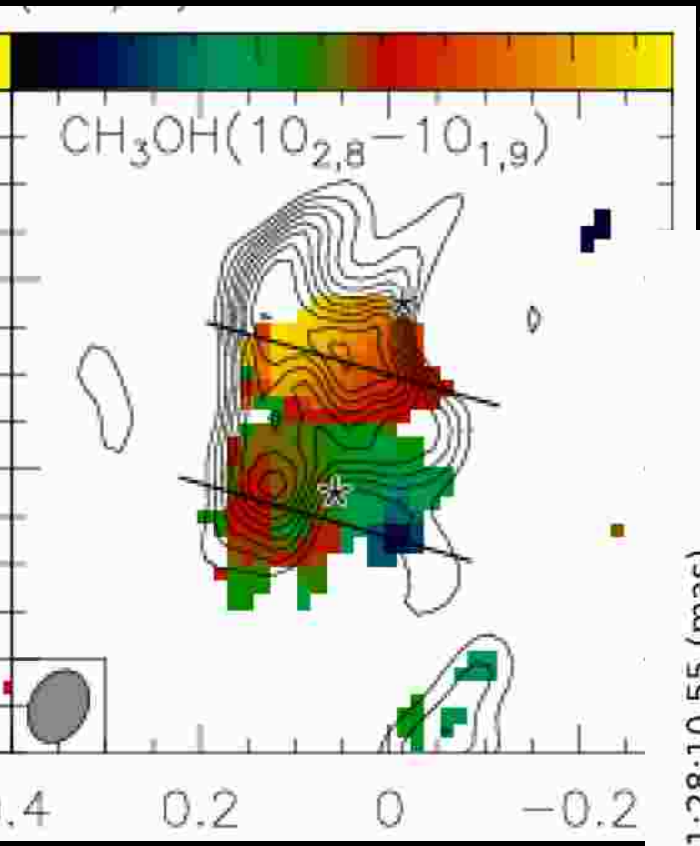

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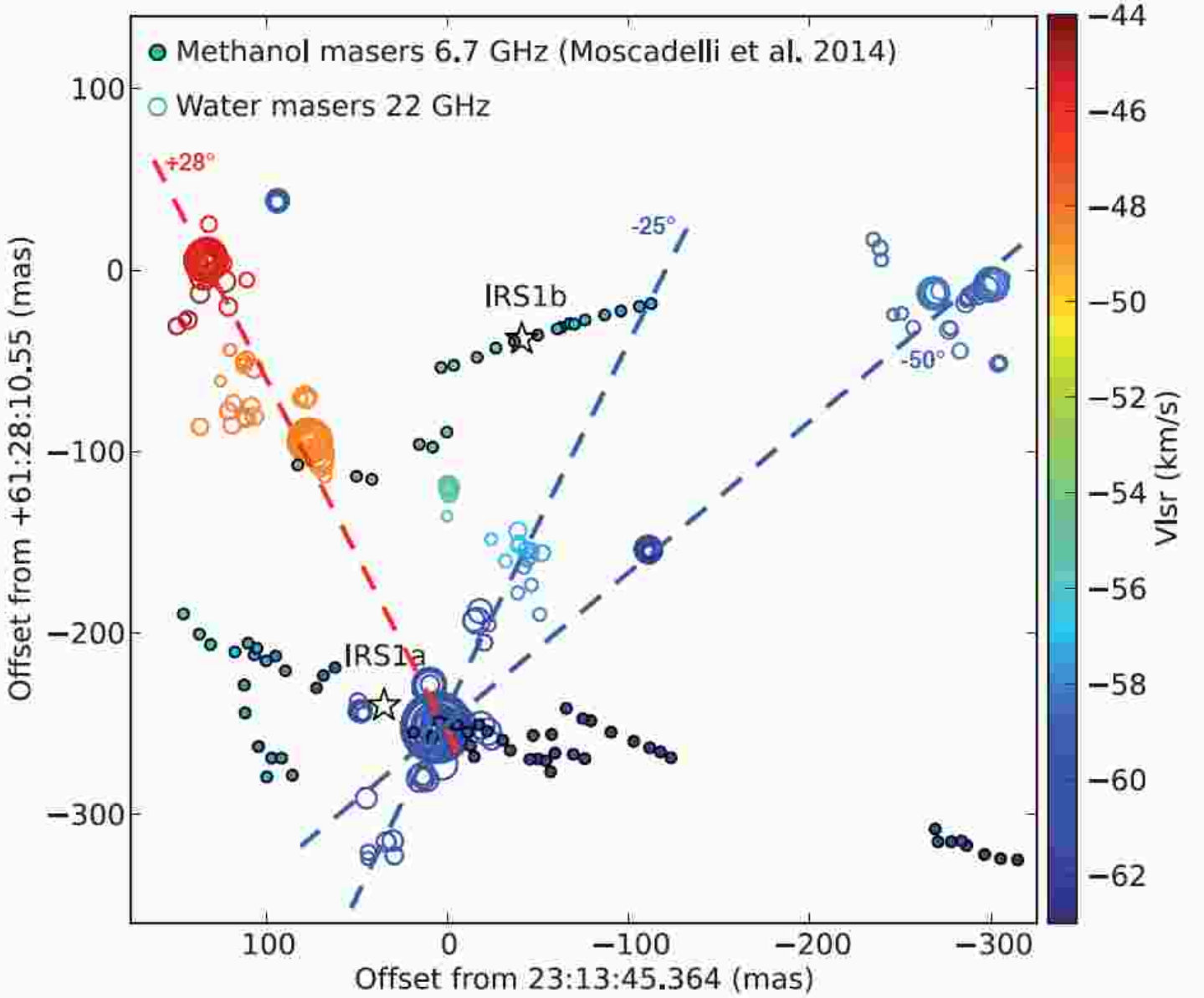
Wide-angle (conical) outflow emerging from IRS1A observed with water masers (e-MERLIN, beam ≈ 20 mas). (Herpin et al. 2017)



CONCLUSIONS

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   a) resolving ambiguities in the interpretation of the l.o.s. velocity pattern.
   b) proper comparison with (ad-hoc) models of massive (proto)stars.

3) Presently, the most detailed view of a high-mass (embedded) YSO can be obtained combining JVLA + ALMA (continuum / line, 0.05”-10”) thermal data with multi-epoch VLBI (milli-arcsec) maser observations.

GRAZIE for your attention !